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Improving the antimicrobial efficacy of organic acids against *Salmonella enterica* attached to chicken skin using SDS with acceptable sensory quality

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ABSTRACT

The objective of the current study was to use sodium dodecyl sulfate (SDS) for enhancing the lethality of organic acids against *Salmonella enterica*, so that lower concentrations of organic acids can effectively eliminate the pathogen from chicken surfaces. Cell suspension of *S. enterica* Kentucky was prepared, attached into the skin and treated by dipping in organic acids (Lactic, Levulinic, and Acetic; 10–20 g/kg), SDS (5–10 g/kg) or their combinations for 1–3 min. Lactic acid revealed the highest bactericidal efficacy, however, levulinic acid showed the lowest bactericidal efficacy. Different combinations of SDS with organic acids resulted in synergistic inactivation of *S. enterica* Kentucky attached to chicken skin. More than 5 log reduction of *S. enterica* Kentucky were achieved by combinations of lactic acid or acetic acid with SDS. Sensory characteristics of chicken drumsticks treated with the most effective combinations of organic acids and SDS were satisfactory. Therefore, combining organic acids specially lactic or acetic with SDS might be suitable for application by chicken processors for effective decontamination of chicken carcasses or cuts.

1. Introduction

Dressed chicken can be contaminated during transportation or by cross contamination throughout processing steps such as scalding, defeathering, evisceration and by slaughtering tools (Allen et al., 2003; Satin, 2002). Microbial contamination is a major cause of quality deterioration of dressed chicken during storage and it may result in transmission of foodborne pathogens that represent public health threats. *Salmonella* is considered as one of the most important pathogenic bacteria that commonly contaminate raw chicken meat (Anang, Rusul, Bakar, & Ling, 2007; ICMSF, 2005). Chicken products were reported to be an essential source for transmission of *Salmonella* to human and several *Salmonella* outbreaks were reported (Bohaychuk et al., 2006; Davies & Breslin, 2003). Chicken skin was considered to be the main site of contamination and the most difficult part to control because it covers the carcass and comes in contact with different contamination sources, moreover, it contains microfolds, feather follicles and microcracks in which, bacteria can attach and colonize (Kim, Frank, & Craven, 1996; Lecompte, Collignan, Sarter, Cardinale, & Kondjoyan, 2009).

The desired decontamination method should be efficient, gentle, and inexpensive as well as it should not affect the quality of the product (Huffman, 2002). Varieties of decontaminating agents have been introduced into the chicken meat processing to reduce the levels of contaminating microorganisms such as chlorine which is widely used during chicken meat processing (Buncic & Sofos, 2012). However, it has been recorded that low levels of chlorine are ineffective against *Salmonella* attached to chicken skin and higher levels, which are effective, resulted in discoloration of the skin, off-flavor of carcass and corrosion of the equipments. Moreover, when chlorine comes in contact with organic matter, it forms carcinogenic chlorinated derivatives (Tamblyn, Conner, & Bilgili, 1997).

Organic acids are generally recognized as safe substances (GRAS) and approved as food preservatives by European committee, FAO/WHO and FDA (Surekha & Reddy, 2000), They are used in chicken meat industries due to their antimicrobial potency, cost-effectiveness, and application simplicity (Cosansu & Ayhan, 2010; Sumarmono & Rahardjo, 2008). However, using

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high concentrations of organic acids, which are efficient against *Salmonella* attached to chicken skin, result in unfavorable carcass changes, such as bleaching of the skin and are expensive to chicken processors. Meanwhile, using low concentrations of organic acids showed only limited effectiveness against *Salmonella* attached to dressed chicken carcasses (Kotula & Thelappurate, 1994; Tamblyn, Conner, & Bilgili, 1994). It has been observed that the attachment or embedding of *Salmonella* in dressed chicken skin increased their resistance to bactericidal effect of organic acids (Lillard, 1988). The topographical structure of chicken skin and its high lipid content are the primary protective factors for microorganisms (Tamblyn & Conner, 1997). Therefore, enhancing organic acid delivery to attached or embedded bacterial cell is important for improving their bactericidal efficacy.

It has been recognized that surfactants have the ability to change the permeability characteristics of biological membranes including skin. Therefore, they can enhance the skin penetration of other compounds present in the formulation (Florence, Tuker, & Walters, 1994; Lopez, Llinares, Cortell, & Herraez, 2000). Sodium dodecyl sulfate (SDS) is one of the transdermal surfactant, which is generally recognized as safe substance (GRAS) (FDA, 2007) and used as an additive in a variety of foods. SDS has the ability to denature proteins and damage cell membranes, and its effectiveness increases with lowering the pH (Zhao, Zhao, & Doyle, 2009).

We hypothesize that combining SDS with organic acids may enhance the penetration of organic acids into the skin feather follicles and microcracks. Therefore, the attached and embedded bacteria will be exposed to lower concentrations of organic acid to increase their bactericidal activity without affecting the carcass sensory quality. In the present study, our main goal was to use SDS for enhancing the bactericidal efficacy of lower concentrations of organic acids against *Salmonella enterica* attached to dressed chicken surface and to evaluate the impact of combinations of SDS and organic acids on the sensory quality of chicken drumsticks after washing.

2. Material and methods

2.1. Preparation of S. enterica Kentucky cell suspension

S. enterica Kentucky with antigenic formula O: 8.20 H.i.Z6, isolated from dressed chicken cuts (collected from local retail markets) and serologically identified in the central health laboratories of ministry of health, Egypt, was used in this study. Cultures were maintained at −18 °C in brain–heart infusion (BHI) (LAB M, 49) containing 100 g/kg glycerol (Sigma–Aldrich, G5516) until use. Stock culture of this microorganism was propagated in tryptic soy broth (Oxoid, CM 129) twice at 37 °C for 24 h before use in the experiments. The culture was harvested by centrifugation at 7600 × g and 4 °C for 15 min and then washed with sterile peptone water (1 g/kg). Centrifugation and washing procedures were repeated twice, and the resulting cell pellet was re-suspended in the peptone water.

2.2. Treatment solutions

Three different organic acids, Lactic acid (LA; Sigma–Aldrich, St. Louis, MO), Levulinic acid (LevA; Merck, Schunchardt, Germany) and Acetic Acid (AA; Sigma–Aldrich, St. Louis, MO) as well as Sodium Dodecyl Sulfate (SDS; Sigma–Aldrich, St. Louis, MO) were used in the experiment.

2.3. Preparation of skin attachment model (SAM)

Fresh chicken breast skin was purchased from a local market. The skin was cut into pieces of 2 × 5 cm and washed several times using sterile distilled water then exposed to UV light at 356 nm for 2 h under U.V. cabinet (Cole-Parmer 9818 Series-Darkroom) to allow removal of background micro-flora. Samples were taken from SAM and examined for presence of *Salmonella* spp. as well as for enumeration of aerobic mesophilic bacteria.

2.4. Inoculation of SAM with S. enterica Kentucky

The SAM (10 cm^2) were inoculated with *S. enterica* Kentucky by immersion in the previously prepared cell suspension containing 9.65 log cfu/mL for 20 min. The SAM were removed from the cell suspension and left for 20 min at room temperature under aseptic condition for attachment. The final inoculation level of *S. enterica* Kentucky on SAM was 8.72 log cfu/cm^2.

2.5. Washing tests of SAM

Twenty treatment solutions were prepared from organic acids (LA, LevA and AA) at concentrations of 10 g/kg and 20 g/kg, SDS at concentrations of 5 g/kg and 10 g/kg, and combinations of different concentrations of organic acids and SDS. The treatment solutions included 3 organic acids × 2 concentrations (6 solutions), SDS (2 concentrations) and combinations of 2 concentrations of each organic acid × 2 concentrations of SDS (12 solutions). Each inoculated SAM was washed with 100 mL of one of test washing solution for either 1 or 3 min in a sterile stomacher bag (12 × 20 cm). An inoculated SAM was placed in bags containing 100 mL sterile distilled water and used as control. Moreover, a blank control of prepared SAM was tested without washing. The bag containing the SAM and washing solution was gently hand massaged every 10 s. The treated SAM was placed immediately in a stomacher bag containing 10 mL sterile peptone water (1 g/kg). The samples were homogenized in stomacher (Lab blender 400, Seward lab. Model No. AB 6021) at high speed for 2 min. Homogenates were subjected to serial dilutions and diluents were surface plated onto standard plate count agar (Oxoid, CM 463). Plates were incubated at 37 °C for 24 h, and survivors were counted. Three independent replications were conducted for each test.

2.6. Most probable number (MPN) technique

SAM treated with combinations of 20 g/kg LA plus 10 g/kg SDS or 20 g/kg AA plus 10 g/kg SDS for 3 min produced survivors not detectable by plating. Therefore, the most-probable-number (MPN) techniques were used to determine the lowest possible *S. enterica* Kentucky count. A cell suspension of *S. enterica* Kentucky was prepared and attached to SAM at level of 4.5 log cfu/cm^2. After attachment of the microorganism, each SAM was placed in sterile stomacher bag containing 100 mL of 20 g/kg LA plus 10 g/kg SDS or 20 g/kg AA plus 10 g/kg SDS and gently massaged for 3 min. Each treated SAM was placed into a sterile stomacher bag containing 10 mL of peptone water (1 g/kg). Individual bags were stomached for 2 min then the mixtures were serially diluted in peptone water (1 g/kg). From each dilution, (1st, 2nd and 3rd dilutions), 3 mL were transferred into 3 tubes containing 9 mL buffered peptone water (1 mL each) and incubated at 37 °C for 24 h. One mL from each of buffered peptone water was inoculated into a sterile tube containing 10 mL of Rappaports Vassiliadis (RV) broth (Oxoid, CM 669) and incubated at 41.5 °C ± 1 °C for 24 h for selective enrichment. Following incubation, a loopful from each RV tube was streaked

onto Xylose–Lysine Desoxycholate (XLD) (Oxoid, CM 469) and incubated at 37 °C 24 h. The number of positive plates (plates with typical *Salmonella* colonies) for each dilution was counted. The MPN values were calculated as described by Peeler, Houhtby, and Rainosek (1992).

2.7. Sensory evaluation

Sensory evaluation was performed using treatment solutions which were proved to be the most effective in inactivation of *S. enterica* Kentucky from Skin attachment model.

2.7.1. Samples and washing tests

Fresh drumsticks were purchased from local retail market and transferred immediately after slaughtering in a cooling ice box to the laboratory. Seven test solutions were prepared and used in this experiment. These solutions included: (1) distilled water (washing control); (2) 10 g/kg LA plus 5 g/kg SDS; (3) 10 g/kg LevA plus 5 g/kg SDS; (4) 10 g/kg AA plus 5 g/kg SDS; (5) 20 g/kg LA plus 10 g/kg SDS; (6) 20 g/kg LevA plus 10 g/kg SDS; (7) 20 g/kg AA plus 10 g/kg SDS. Chicken drumsticks (~100 g each) were washed with 200 mL by one of 7 test washing solutions for 3 min in a large stomacher bag with gentle massaging.

2.7.2. Sensory evaluation

Treated drumsticks were sensory evaluated immediately after treatment or every 2 days during refrigerated storage until signs of deterioration became evident. Sensory evaluation was performed in raw treated drumstick or drumsticks cooked in a forced draught oven at 220 °C for 30 min according to the schemes of Sumarmono and Rahardjo (2008), Baston and Barna (2010) and Kenawi (2005). For sensory evaluation of treated drumsticks, nine experienced panelists (from both sexes in the age range of 25–40 years) were chosen from the staff members of the Department of Food Hygiene and Control at Faculty of Veterinary Medicine, Cairo University, Egypt. Panelists were selected on the basis of previous experience in consuming dressed chicken. Moreover, they received a preparatory session prior to testing, so that each panelist could thoroughly discuss and clarify each attribute to be evaluated. The panelists evaluated treated raw drumsticks in a randomized order and asked to assign a numerical value between 1 and 7 for the following attributes color, odor, slimness and texture where 1 is very poor (I dislike it very much) and 7 is excellent (I like it very much). After cooking, the panelists were asked to assign the same numerical values for the following attributes: Color 1 (very poor) – 7 (excellent); Flavor 1 (imperceptible) – 7 (extremely intense); tenderness 1 (extremely soft) – 7 (extremely tough) and juiciness 1 (extremely dry) – 7 (extremely moist). Tap water was provided between samples to cleanse the palate. At the end of evaluation of each cooked drumstick, each panelist was asked to give a score for overall acceptability from 1 (dislike very much) to 7 (like very much).

2.8. Statistical analysis

All experiments were executed independently three times. Microbial counts (cfu/g) were log transferred before statistical analysis. The data were given as means ± standard deviations. All data were statistically analyzed by ANOVA using SPSS 17.0 for windows (SPSS Inc, Chicago, IL, USA). Multiple comparisons of means were done using least significant difference (LSD) at 5% significance level ($P < 0.05$).

3. Results and discussion

Allowing organic acids to come in contact with the bacterial cell embedded in chicken skin is very important for improving their bactericidal efficacy. The proposed approach to address this problem is combining SDS with organic acids. The goal was to expose bacteria embedded in feather follicles to lower concentrations of organic acids by combining them with SDS, therefore increasing their bactericidal efficacy and keeping the sensory quality of dressed chicken. *S. enterica* Kentucky was used in this study as a surrogate serovar because it is frequently isolated from chicken and it exhibited inactivation resistance to washing solutions similar to *S. enterica* serovars Typhimurium, Senftenberg and Enteritidis (Li et al., 2007; Lu & Wu, 2010, 2012).

3.1. Washing tests of S. enterica Kentucky attached to SAM

Results of inactivation of *S. enterica* Kentucky by different concentrations of organic acids are represented in Table 1. It is obvious from the obtained data that LA revealed the highest bactericidal efficacy and LevA showed the lowest bactericidal efficacy. Increasing the contact time from 1 min to 3 min resulted in significant ($P < 0.05$) reduction of the pathogen. Previously, different authors obtained different reduction rates after treatment with different concentrations of organic acids. Reduction rates of 1.6 and 2.2 log in the count of *Salmonella typhimurium* were obtained after spraying chicken carcasses with lactic acid 10 g/kg for 90 and 20 g/kg for 30 s, respectively (Li, Slavik, Walker, & Xiong, 1997; Xiong, Li, Slavik, & Walker, 1998; Yang, Li, & Slavik, 1998). Chuanchuen, Koowatananukul, Rugkhaw, and Damrongwatanapokin (2004) obtained reduction rates of 1.23, 1.38, 1.70 and 1.07, 1.20, 1.29 log cfu/cm^2 after dipping chicken skin in acetic and lactic acids 24 g/kg for 1, 3 and 5 min, respectively. Lecompte et al. (2009) observed 2.38 log reductions in the count of *Salmonella enteritidis* after 7 days treatment with lactic acid 50 g/kg. Killinger, Kannan, Bary, and Cogger (2010) observed reduction of *Salmonella* attached to chicken wings from 5.78 log cfu/wing to 0.39 log cfu/wing after treatment with lactic 20 g/kg for 3 min. Reduction rates of 1.07, 1.26 and 1.19 log in the counts of *Salmonella* were obtained after treatment with lactic, levulinic and acetic acid 20 g/kg, respectively (Carpenter, Smith, & Broadbent, 2011).

Table 1
Reduction rates (log cfu/cm^2) of *Salmonella enterica* Kentucky attached to skin attachment model (10 cm^2) when treated with organic acids or sodium dodecyl sulfate (SDS) for 1 and 3 min.

Treatment time	Organic acids (10 g/kg)			Organic acids (20 g/kg)			SDS	
	Lactic acid	Levulinic acid	Acetic acid	Lactic acid	Levulinic acid	Acetic acid	5 g/kg	10 g/kg
1 min	2.05 ± 0.13^{Aa}	1.23 ± 0.23^{B}	1.96 ± 0.04^{A}	3.24 ± 0.06^{C}	1.44 ± 0.04^{B}	2.90 ± 0.04^{C}	0.21 ± 0.19^{D}	0.24 ± 0.06^{D}
3 min	3.36 ± 0.14^{A}	2.17 ± 0.34^{B}	1.99 ± 0.22^{B}	5.01 ± 0.05^{C}	1.88 ± 0.15^{B}	2.53 ± 0.47^{B}	0.36 ± 0.04^{D}	0.66 ± 0.08^{E}

[A–E]Values with different superscripts within the same raw are significantly ($P < 0.05$) different.
[a] Data represent average of three independent repeats plus standard deviation.

Treatment of experimentally inoculated SAM with SDS at concentrations of 5 g/kg and 10 g/kg for 1 and 3 min resulted in non-significant ($P > 0.05$) reduction of the pathogen (Table 1). These results were in a good agreement with Tamblyn and Conner (1997) who did not obtain any inhibitory effect of SDS on chicken skin inoculated with *Salmonella*. Less than 5 g/kg log cfu/mL obtained after treating *S. enteritidis* in broth culture with 5 g/kg SDS for 30 min (Zhao et al., 2009). Moreover, it has been reported that many bacteria of family Enterobacteriacae can tolerate the presence of 50 g/kg SDS (Kramer, Nickerson, Hamlett, & O'Hara, 1984; Rajagopal, Sudarsan, & Nickerson, 2002).

Compared with organic acid alone (10 g/kg and 20 g/kg for 1 and 3 min), combinations of SDS (5 g/kg and 10 g/kg) and organic acids resulted in a significantly greater lethality against the pathogen. Reduction rates obtained after treatment of *S. enterica* Kentucky attached to SAM with different combinations of organic acids and SDS were statistically compared with the sum of values obtained when organic acid and SDS were applied alone (Tables 2–4). The values of reduction rates obtained due to treatment with combinations of organic acids with SDS were significantly ($P < 0.05$) higher than those obtained by sum of organic acid alone plus SDS alone, indicating that combining organic acids (10 g/kg and 20 g/kg for 1 and 3 min) with SDS (5 g/kg and 10 g/kg for 1 or 3 min) resulted in synergistic effects against *S. enterica* Kentucky attached to chicken skin. It is clear in this study that the ratio of organic acids to SDS played an important role in the inactivation of *S. enterica* Kentucky attached to skin. Generally, we observed that combining organic acids with SDS at ratio of 2:1 resulted in higher reduction rate.

It is important to point out that *S. enterica* Kentucky attached to skin and treated with combinations of 20 g/kg LA plus 10 g/kg SDS for 3 min or AA 20 g/kg plus 10 g/kg SDS for 3 min produced survivors not detectable by conventional plating procedure. The MPN for *S. enterica* Kentucky survivors attached to SAM (4.5 log cfu/cm^2) and treated with these combinations was <0.3 per cm^2 indicating that more than 5 log reductions were achieved when *S. enterica* Kentucky attached to SAM was treated with 20 g/kg LA or AA plus 10 g/kg SDS for 3 min.

3.2. Mechanism of action

It has been established that the primary mechanism of microbial inactivation by organic acids involves entrance of un-dissociated form of organic acid (HA) across the cell membrane and dissociation into (H+) and (A−) ions. H+ ion is responsible for shifting the nearly neutral pH of the cytoplasm, which is normal media for optimum performance of cell organelles and cell enzymes, to acidic side. Increasing the acidity of the cytoplasm leads to cell damage and modification or denaturation of enzymes and structural proteins as well as hindering DNA/RNA synthesis. Moreover, increasing the acidity of cytoplasm forces the cell to use the ATP to export the excess (H+) ion leading to energy depletion with subsequent hindering of microbial growth and cell death (Mani-López, García, &

Table 2
Reduction rates (log cfu/cm^2) of *Salmonella enterica* Kentucky attached to skin attachment model (10 cm^2) when treated with different combinations of lactic acid (LA) with sodium dodecyl sulfate (SDS) for 1 and 3 min.

Treatment time	Lactic acid (10 g/kg)				Lactic acid (20 g/kg)			
	Sum LA alone + SDS (5 g/kg) alone	Combination of LA with SDS (5 g/kg)	Sum LA alone + SDS (10 g/kg) alone	Combination of LA with SDS (10 g/kg)	Sum LA alone + SDS (5 g/kg) alone	Combination of LA with SDS (5 g/kg)	Sum LA alone + SDS (10 g/kg) alone	Combination of LA with SDS (10 g/kg)
1 min	2.26 ± 0.13^{Aa}	4.79 ± 0.74^{B}	2.29 ± 0.05^{A}	5.45 ± 0.01^{C}	3.45 ± 0.09^{D}	5.01 ± 1.31^{C}	3.48 ± 0.07^{D}	6.80 ± 0.68^{E}
3 min	3.72 ± 0.03^{A}	6.85 ± 0.09^{B}	4.02 ± 0.03^{A}	6.25 ± 0.96^{B}	5.37 ± 0.14^{C}	6.63 ± 0.17^{B}	5.67 ± 0.06^{C}	7.43 ± 0.07^{D}

$^{A–E}$Values with different superscripts within the same raw are significantly ($P < 0.05$) different.
[a] Data represent average of three independent repeats plus standard deviation.

Table 3
Reduction rates (log cfu/cm^2) of *Salmonella enterica* Kentucky attached to skin attachment model (10 cm^2) when treated with different combinations of levulinic acid (LevA) with sodium dodecyl sulfate (SDS) for 1 and 3 min.

Treatment time	Levulinic acid (10 g/kg)				Levulinic acid (20 g/kg)			
	Sum Lev alone + SDS (5 g/kg) alone	Combination of LevA with SDS (5 g/kg)	Sum Lev alone + SDS (10 g/kg) alone	Combination of LevA with SDS (10 g/kg)	Sum Lev alone + SDS (5 g/kg) alone	Combination of LevA with SDS (5 g/kg)	Sum Lev alone + SDS (10 g/kg) alone	Combination of LevA with SDS (10 g/kg)
1 min	1.44 ± 0.04^{Aa}	3.92 ± 0.04^{B}	1.47 ± 0.14^{A}	2.58 ± 0.12^{C}	1.65 ± 0.01^{A}	3.13 ± 0.20^{D}	1.68 ± 0.09^{A}	4.10 ± 0.57^{B}
3 min	2.53 ± 0.27^{A}	4.54 ± 0.36^{B}	2.83 ± 0.19^{A}	3.89 ± 0.32^{B}	2.24 ± 0.28^{A}	3.76 ± 0.04^{B}	2.54 ± 0.18^{A}	5.76 ± 0.03^{C}

$^{A–D}$Values with different superscripts within the same raw are significantly ($P < 0.05$) different.
[a] Data represent average of three independent repeats plus standard deviation.

Table 4
Reduction rates (log cfu/cm^2) of *Salmonella enterica* Kentucky attached to skin attachment model (10 cm^2) when treated with different combinations of acetic acid (AA) with sodium dodecyl sulfate (SDS) for 1 and 3 min.

Treatment time	Acetic acid (10 g/kg)				Acetic acid (20 g/kg)			
	Sum AA alone + SDS (5 g/kg) alone	Combination of AA with SDS (5 g/kg)	Sum AA alone + SDS (10 g/kg) alone	Combination of AA with SDS (10 g/kg)	Sum AA alone + SDS (5 g/kg) alone	Combination of AA with SDS (5 g/kg)	Sum AA alone + SDS (10 g/kg) alone	Combination of AA with SDS (10 g/kg)
1 min	2.17 ± 0.12^{Aa}	4.43 ± 0.06^{B}	2.20 ± 0.29^{A}	3.53 ± 0.04^{C}	2.81 ± 0.41^{A}	4.91 ± 0.54^{B}	2.84 ± 0.17^{A}	5.51 ± 0.19^{D}
3 min	2.35 ± 0.26^{A}	6.27 ± 0.22^{B}	2.65 ± 0.21^{A}	4.78 ± 0.43^{C}	2.89 ± 0.18^{A}	5.93 ± 0.30^{B}	3.19 ± 0.25^{D}	7.43 ± 0.07^{E}

$^{A–E}$Values with different superscripts within the same raw are significantly ($P < 0.05$) different.
[a] Data represent average of three independent repeats plus standard deviation.

López-Malo, 2012; Ricke, 2003; Van Immerseel et al., 2006). SDS has the ability to denature protein surfaces and damage cell membrane. The bactericidal effect of SDS can be increased at lower pH between 1.5 and 3.0. Therefore the anti-microbial properties of SDS can be enhanced by mixing SDS with organic acid (Anderson, Day, Russell, & White, 1990; Byelashov, Kendall, Belk, Scanga, & Sofos, 2008; Tamblyn & Conner, 1997).

We proposed that the mechanism of synergistic bacterial inactivation obtained by combination of SDS and organic acids may be explained as follow: Treating skin with organic acids reduces the pH to 3.0 which enhances the activity of SDS. SDS, which is more active at acidic pH, has an amphiphilic property (anionic surfactant) which is able to denature proteins and dissolve fats of the skin follicles (Bales, Messina, Vidal, Peric, & Nascimento, 1998). Furthermore, SDS as a penetration enhancer can partition into and interacts with the corneum layer (the out most layer of the skin) components and induce a temporary reversible increase in the skin permeability (Shokri et al., 2001). Therefore, SDS allows the delivery of organic acid to attack the *S. enterica* Kentucky embedded in the skin follicles, with subsequent higher reduction rates of bacterial populations after combining SDS with organic acids.

3.3. Sensory evaluation

Sensory attributes are the most important factors that influence the perception of meat and meat products by consumers and manufacturers. Consumer acceptance of meat depends mainly on the appearance, odor, and texture of the product. In the current study, we chose the most effective combination treatments of organic and SDS that resulted in significant reduction in the populations of *S. enterica* Kentucky to be evaluated for sensory attributes. Some sensory attributes especially odor become more evident after cooking of the product, therefore we evaluated the sensory attributes of raw and cooked treated chicken drumsticks.

The results of sensory attributes of raw and cooked drumsticks treated with combinations of organic acids and SDS are illustrated in Tables 5 and 6. The sensory score (color, odor, sliminess and texture) of raw chicken drumsticks treated with different combinations of organic acids and SDS evaluated immediately after treatments (0 day) revealed non-significant ($P > 0.05$) changes from those of control (samples dipped in distilled water). Cooking of drumsticks immediately after treatment (0-day) resulted in non-significant ($P > 0.05$) difference in sensory scores of color, juiciness and tenderness. Panelist detected a slight acidic odor in samples treated with combinations of 20 g/kg LA and 10 g/kg SDS immediately after cooking, therefore, the flavor score of this combination treatment was significantly ($P < 0.05$) lower than those of control but still within the acceptable level. This acidic odor disappeared within few minutes. The flavor scores of other treatments were non-significantly ($P > 0.05$) different from those of control. Acidulous odor was reported by Gulmez, Oral, and Vatansever (2006) after treatment of chicken wings with lactic acid 20 g/kg for 10 min. The overall acceptability scores of all treatments were non-significantly ($P > 0.05$) different from those of control samples. Changes in skin color such as darkening, bleaching or whitening were recorded by many authors after treatment with AA or LA for more than 10 min or by concentrations more than 20 g/kg (Burfoot & Mulvey, 2011; Dickens & Whittemore, 1994; Gulmez et al., 2006; Izat, Colbana, Adam, Reiler, & Waldrop, 1989; Nassar, Al-Mashhadi, Fawal, & Shalhat, 1997). However, the color and texture values of chicken breast remained non-significantly ($P > 0.05$) different from control after treatment with 2 mg/mL acetic acid and 0.2 mg/mL thymol in combination with 50 g/kg SDS (Lu & Wu, 2012).

Food processors are concerned about potential changes when treated products are held in storage. Therefore, drumsticks, treated with different combinations of organic acids and SDS, were stored at 5 °C and the sensory attributes were assessed every 2 day during chilled storage until the deterioration signs became evident. At the third day of storage, the sensory scores of all treated raw samples were significantly ($P < 0.05$) higher than those of control. The odor and sliminess scores of control samples were under the acceptable scores (3.5). After cooking, the scores of flavor, juiciness, tenderness and overall acceptability of treated samples were significantly ($P < 0.05$) higher than those of control. The sensory scores of treated raw and cooked samples were within the acceptable limit at the 5th of storage. Meanwhile, the control samples revealed the characteristic signs of deterioration. By the 7th day of storage, the signs of deterioration were evident in all treated samples. Therefore, treatment of chicken drumsticks with combinations of organic

Table 5
Sensory scores of raw chicken drumsticks, after treatment with combinations of organic acids and sodium dodecyl sulfate for 3 min, immediately and during chilled storage.

Sensory scores, mean ± SD							
Sensory attributes	Water (control)	5 g/kg SDS			10 g/kg SDS		
		10 g/kg LA	10 g/kg LEV.A.	10 g/kg AA	10 g/kg LA	10 g/kg LEV.A.	10 g/kg AA
0 day							
Color	6.20 ± 0.45^{a}	5.80 ± 0.84^{a}	6.00 ± 0.71^{a}	6.00 ± 0.71^{a}	5.40 ± 0.89^{a}	6.00 ± 0.71^{a}	5.80 ± 0.84^{a}
Odor	5.20 ± 0.50^{a}	5.60 ± 0.55^{a}	5.60 ± 0.55^{a}	5.20 ± 1.79^{a}	4.40 ± 0.89^{a}	5.40 ± 0.89^{a}	5.20 ± 0.45^{a}
Slimness	6.20 ± 0.84^{a}	6.40 ± 0.55^{a}	6.40 ± 0.55^{a}	6.40 ± 0.55^{a}	6.40 ± 0.55^{a}	6.40 ± 0.55^{a}	6.40 ± 0.55^{a}
Texture	6.20 ± 0.84^{a}	6.20 ± 0.84^{a}	6.20 ± 0.84^{a}	6.20 ± 0.84^{a}	6.20 ± 0.84^{a}	5.60 ± 1.14^{a}	6.20 ± 0.84^{a}
3rd day							
Color	4.80 ± 0.45^{a}	5.80 ± 0.45^{b}	6.00 ± 0.00^{b}	6.00 ± 0.00^{b}	5.80 ± 0.45^{b}	6.00 ± 0.00^{b}	5.60 ± 0.55^{b}
Odor	2.20 ± 1.20^{a}	6.00 ± 0.00^{b}	5.80 ± 0.45^{b}	6.00 ± 0.00^{b}	5.00 ± 0.00^{b}	6.00 ± 0.00^{b}	5.20 ± 0.84^{b}
Slimness	3.00 ± 1.00^{a}	5.80 ± 0.45^{b}	5.80 ± 0.45^{b}	5.40 ± 0.55^{b}	5.40 ± 0.55^{b}	5.80 ± 0.45^{b}	5.40 ± 0.55^{b}
Texture	4.60 ± 0.89^{a}	6.00 ± 0.00^{b}	5.60 ± 0.55^{a,b}	5.60 ± 0.55^{a,b}	5.60 ± 0.55^{a,b}	5.80 ± 0.45^{b}	5.80 ± 0.455^{b}
5th day							
Color	1.40 ± 0.89^{a}	4.40 ± 1.67^{b}	5.00 ± 1.73^{b}	4.40 ± 0.55^{b}	4.60 ± 1.52^{b}	5.20 ± 1.20^{b}	4.60 ± 1.34^{b}
Odor	1.00 ± 0.00^{a}	4.60 ± 1.34^{b}	4.60 ± 1.34^{b}	4.60 ± 1.52^{b}	4.60 ± 1.67^{b}	4.40 ± 1.52^{b}	4.60 ± 1.52^{b}
Slimness	1.00 ± 0.00^{a}	4.20 ± 1.48^{b}	4.40 ± 0.89^{b}	4.80 ± 1.30^{b}	4.60 ± 1.14^{b}	5.00 ± 1.41^{b}	4.80 ± 1.30^{b}
Texture	1.40 ± 0.89^{a}	5.20 ± 0.84^{b}	5.40 ± 0.89^{b}	5.20 ± 0.84^{b}	5.40 ± 0.89^{b}	5.40 ± 0.89^{b}	5.20 ± 0.84^{b}

$^{a-b}$Values with different superscripts within the same raw (for each sensory attribute) are significantly ($P < 0.05$) different.
LA, lactic acid; LevA, levulinic acid; AA, acetic acid.

Table 6
Sensory scores of cooked chicken drumsticks, after treatment with combinations of organic acids and sodium dodecyl sulfate for 3 min, immediately and during chilled storage.

Sensory scores, mean ± SD							
Sensory attributes	Water (control)	5 g/kg SDS			10 g/kg SDS		
		10 g/kg LA	10 g/kg LEV.A.	10 g/kg AA	10 g/kg LA	10 g/kg LEV.A.	10 g/kg AA
0 day							
Color	6.40 ± 0.55^{a}	6.20 ± 0.84^{a}	6.00 ± 0.71^{a}	6.20 ± 0.45^{a}	6.20 ± 0.84^{a}	6.40 ± 0.55^{a}	6.20 ± 0.45^{a}
Flavor	6.60 ± 0.55^{a}	6.40 ± 0.55^{a,b}	5.80 ± 1.20^{a,b}	6.20 ± 0.45^{a,b}	4.60 ± 1.34^{b}	6.00 ± 1.00^{a,b}	5.40 ± 1.14^{a,b}
Juiciness	5.60 ± 0.89^{a}	6.80 ± 0.45^{a}	6.60 ± 0.55^{a}	6.60 ± 0.55^{a}	6.00 ± 0.00^{a}	6.20 ± 0.84^{a}	6.60 ± 0.55^{a}
Tenderness	5.60 ± 0.89^{a}	6.80 ± 0.45^{a}	6.80 ± 0.45^{a}	6.60 ± 0.55^{a}	6.20 ± 0.45^{a}	6.60 ± 0.55^{a}	6.60 ± 0.55^{a}
Overall	6.05 ± 0.67^{a}	6.55 ± 0.51^{a}	6.30 ± 0.48^{a}	6.40 ± 0.38^{a}	5.75 ± 0.45^{a}	6.30 ± 0.69^{a}	6.10 ± 0.65^{a}
3rd day							
Color	5.40 ± 0.55^{a}	6.00 ± 0.00^{a}	6.20 ± 0.45^{a}	5.80 ± 0.45^{a}	6.00 ± 0.00^{a}	6.20 ± 0.45^{a}	5.80 ± 0.45^{a}
Flavor	3.80 ± 1.20^{a}	6.40 ± 0.55^{b}	6.00 ± 0.71^{b}	5.80 ± 0.45^{b}	6.00 ± 0.71^{b}	6.20 ± 0.84^{b}	5.40 ± 0.55^{b}
Juiciness	3.00 ± 1.58^{a}	6.60 ± 0.55^{b}	6.60 ± 0.89^{b}	5.80 ± 0.45^{b}	6.80 ± 0.45^{b}	6.40 ± 0.55^{b}	5.80 ± 0.45^{b}
Tenderness	3.40 ± 1.52^{a}	6.60 ± 0.55^{b}	6.80 ± 0.45^{b}	5.80 ± 0.45^{b}	6.60 ± 0.55^{b}	6.40 ± 0.55^{b}	5.80 ± 0.45^{b}
Overall	3.90 ± 0.76^{a}	6.40 ± 0.38^{b}	6.40 ± 0.45^{b}	5.80 ± 0.27^{b}	6.35 ± 0.38^{b}	6.30 ± 0.54^{b}	5.70 ± 0.21^{b}
5th day							
Color	1.60 ± 1.34^{a}	6.00 ± 0.00^{b}	6.00 ± 0.00^{b}	4.20 ± 1.20^{c}	6.00 ± 0.00^{b}	6.00 ± 0.00^{b}	5.80 ± 0.45^{b}
Flavor	1.00 ± 0.00^{a}	4.40 ± 0.55^{b,c}	5.40 ± 0.54^{b}	3.60 ± 0.55^{c}	5.40 ± 0.55^{b}	4.80 ± 0.45^{b}	4.60 ± 0.55^{b,c}
Juiciness	1.00 ± 0.00^{a}	6.60 ± 0.54^{b}	6.60 ± 0.89^{b}	5.80 ± 0.45^{b}	6.80 ± 0.44^{b}	6.40 ± 0.55^{b}	5.80 ± 0.45^{b}
Tenderness	1.00 ± 0.00^{a}	6.60 ± 0.54^{b,c}	6.80 ± 0.45^{b}	5.80 ± 0.45^{c}	6.60 ± 0.55^{b,c}	6.40 ± 0.55^{b,c}	5.80 ± 0.45^{c}
Overall	1.15 ± 0.34^{a}	5.90 ± 0.14^{b,c}	6.20 ± 0.27^{b}	4.85 ± 0.49^{d}	6.20 ± 0.33^{b}	5.90 ± 0.22^{b,c}	5.50 ± 0.18^{c}

$^{a-d}$Values with different superscripts within the same raw are significantly ($P < 0.05$) different.
LA, lactic acid; LevA, levulinic acid; AA, acetic acid.

acids and SDS increased the shelf life of these drumsticks for 4 days at chilling temperature.

4. Conclusion

SDS (5–10 g/kg) synergistically enhanced organic acids for inactivation of *S. enterica* Kentucky. Combinations of organic acids with SDS are more effective when the ratio of organic acid to SDS was 2:1. More than 5 log reduction of *S. enterica* Kentucky can be achieved by combinations of lactic acid or acetic acid with SDS. Sensory characteristics of chicken cuts treated with combinations of organic acids and SDS were satisfactory. Therefore, combining organic acids specially lactic or acetic with SDS might be suitable for application by chicken processors for effective decontamination of chicken carcasses or cuts.

References

Allen, V. M., Hinton, M. H., Tinker, D. B., Gibson, C., Mead, G. C., & Wathes, C. M. (2003). Microbial cross-contamination by airborne dispersion and contagion during defeathering of poultry. *British Poultry Science, 44*, 567–576.

Anang, D. M., Rusul, G., Bakar, J., & Ling, F. H. (2007). Effects of lactic acid and lauricidin on the survival of *Listeria monocytogenes*, *Salmonella enteritidis* and *Escherichia coli* O157:H7 in chicken breast stored at 4 °C. *Food Control, 18*, 961–969.

Anderson, D. J., Day, M. J., Russell, N. J., & White, G. F. (1990). Die-away kinetic analysis of the capacity of epilithic and planktonic bacteria from clean and polluted river water to biodegrade sodium dodecyl sulfate. *Applied and Environmental Microbiology, 56*, 758–763.

Bales, B. L., Messina, L., Vidal, A., Peric, M., & Nascimento, O. R. (1998). Precision relative aggregation number determinations of SDS micelles using a spin probe. A model of micelle surface hydration. *Journal of Physical Chemistry, 102*, 10347–10358.

Baston, O., & Barna, O. (2010). Raw chicken leg and breast sensory evaluation. *Annals Food Science and Technology, 11*, 25–30.

Bohaychuk, V. M., Gensler, G. E., King, R. K., Manninen, K. I., Sorensen, O., Wu, J. T., et al. (2006). Occurrence of pathogens in raw and ready to eat meat and poultry products collected from the retail marketplace in Edmonton, Alberta, Canada. *Journal of Food Protection, 69*, 2176–2182.

Buncic, S., & Sofos, J. (2012). Interventions to control *Salmonella* contamination during poultry, cattle and pig slaughter. *Food Research International, 45*, 641–655.

Burfoot, D., & Mulvey, E. (2011). Reducing microbial counts on chicken and turkey carcasses using lactic acid. *Food Control, 22*, 1729–1735.

Byelashov, O. A., Kendall, P. A., Belk, K. E., Scanga, J. A., & Sofos, J. N. (2008). Control of *Listeria monocytogenes* on vacuum-packaged frankfurters sprayed with lactic acid alone or in combination with sodium lauryl sulfate. *Journal of Food Protection, 71*, 728–734.

Carpenter, C. E., Smith, J. V., & Broadbent, J. R. (2011). Efficacy of washing meat surfaces with 2% levulinic, acetic, or lactic acid for pathogen decontamination and residual growth inhibition. *Meat Science, 88*, 256–260.

Chuanchuen, R., Koowatananukul, C., Rugkhaw, V., & Damrongwatanapokin, T. (2004). In vitro effects of sodium hypochlorite, trisodium phosphate and organic acids on the decontamination of *Salmonella enterica* serovar *Enteritidis* on chicken skin. *Thai Journal of Veterinary Medicine, 34*, 33–43.

Cosansu, S., & Ayhan, K. (2010). Effects of lactic and acetic acid treatments on *Campylobacter jejuni* inoculated onto chicken leg and breast meat during storage at 4 °C and −18 °C. *Journal of Food Processing and Preservation, 34*, 98–113.

Davies, R. H., & Breslin, M. F. (2003). Observations on the distribution and persistence of *Salmonella enterica* serovar *Enteritidis* phage type 29 on a cage layer farm before and after the use of competitive exclusion treatment. *British Poultry Science, 44*, 551–557.

Dickens, J. A., & Whittemore, A. D. (1994). The effect of acetic acid and air injection on appearance, moisture pick-up, microbiological quality, and *Salmonella* incidence on processed poultry carcasses. *Poultry Science, 73*, 582–586.

FDA "U.S. Food and Drug Administration". (2007). Food additives permitted for direct addition to food for human consumption. Sodium lauryl sulfate. Available at http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=172.822 Accessed 16.09.13.

Florence, T., Tuker, I. G., & Walters, K. A. (1994). Interaction of non-ionic alkyl and aryl ethers with membranes and other biological systems. In M. J. Rosen (Ed.), *ACS symp. ser.: Vol. 253. Structure performance relationships in surfactants* (pp. 189–207).

Gulmez, M., Oral, N., & Vatansever, L. (2006). The effect of water extract of sumac (*Rhus coriaria* L.) and lactic acid on decontamination and shelf life of raw broiler wings. *Poultry Science, 85*, 1466–1471.

Huffman, R. D. (2002). Current and future technologies for the decontamination of carcasses and fresh meat. *Meat Science, 62*, 285–294.

ICMSF "International Commission on Microbiological Specifications for Foods". (2005). *Microorganisms in foods 6* (2nd ed., p. 766). New York, NY: Kluwer Academic/Plenum Publishers.

Izat, A. Z., Colbana, M., Adam, M. H., Reiler, M. A., & Waldrop, P. M. (1989). Production and processing studies to reduce the incidence of *Salmonella* on commercial broiler. *Journal of Food Protection, 52*, 670–673.

Kenawi, M. A. (2005). Technological, chemical, sensory, and microbiological examination of frozen chicken as affected by microwave thawing. *Biotechnology in Animal Husbandry, 21*, 99–108.

Killinger, K. M., Kannan, A., Bary, A. I., & Cogger, C. G. (2010). Validation of a 2 percent lactic acid antimicrobial rinse for mobile poultry slaughter operations. *Journal of Food Protection, 73*, 2079–2083.

Kim, K. Y., Frank, J. F., & Craven, S. E. (1996). Three-dimensional visualization of *Salmonella* attachment to poultry skin using confocal scanning laser microscopy. *Letters in Applied Microbiology, 22*, 280–282.

Kotula, K., & Thelappurate, R. (1994). Microbiological and sensory attributes of retail cuts of beef treated with acetic and lactic acid solutions. *Journal of Food Protection, 57*, 665–670.

Kramer, V. C., Nickerson, K. W., Hamlett, N. V., & O'Hara, C. (1984). Prevalence of extreme detergent resistance among the Enterobacteriaceae. *Canadian Journal of Microbiology, 30*, 711–713.

Lecompte, J. Y., Collignan, A., Sarter, S., Cardinale, E., & Kondjoyan, A. (2009). Decontamination of chicken skin surfaces inoculated with *Listeria innocua*, *Salmonella enteritidis* and *Campylobacter jejuni* by contact with a concentrated lactic acid solution. *British Poultry Science, 50*, 307–317.

Lillard, H. S. (1988). Effect of surfactant or changes in ionic strength on the attachment of *Salmonella typhimurium* to poultry skin and muscle. *Journal of Food Science, 53*, 727–730.

Li, X., Payne, J. B., Santos, F. B., Levine, J. F., Anderson, K. E., & Sheldon, B. W. (2007). *Salmonella* populations and prevalence in layer feces from commercial high-rise houses and characterization of the *Salmonella* isolates by serotyping, antibiotic resistance analysis, and pulsed field gel electrophoresis. *Poultry Science, 86*, 591–597.

Li, Y., Slavik, M. F., Walker, J. T., & Xiong, H. (1997). Pre-chill spray of chicken carcasses to reduce *Salmonella typhimurium*. *Journal of Food Science, 62*, 605–607.

Lopez, A., Llinares, F., Cortell, C., & Herraez, M. (2000). Comparative enhancer effects of span 20 with Tween 20 and Azone on the in vitro percutaneous penetration of compounds with different lipophilicities. *International Journal of Pharmaceutics, 202*, 133–140.

Lu, Y., & Wu, C. (2010). Reduction of *Salmonella enterica* contamination on grape tomatoes by washing with thyme oil, thymol and carvacrol as compared with chlorine treatment. *Journal of Food Protection, 73*, 2270–2275.

Lu, Y., & Wu, C. (2012). Reductions of *Salmonella enterica* on chicken breast by thymol, acetic acid, sodium dodecyl sulfate or hydrogen peroxide combinations as compared to chlorine wash. *International Journal of Food Microbiology, 152*, 31–34.

Mani-López, E., García, H. S., & López-Malo, A. (2012). Organic acids as antimicrobials to control *Salmonella* in meat and poultry products. *Food Research International, 45*, 713–721.

Nassar, T. J., Al-Mashhadi, A. S., Fawal, A. K., & Shalhat, A. F. (1997). Decontamination of chicken carcasses artificially contaminated with *Salmonella*. *Revue Scientifique et Technique (International Office of Epizootics), 16*, 891–897.

Peeler, J. T., Houhtby, G. A., & Rainosek, A. P. (1992). The mostprobable number-technique. In C. Vanderzant, & D. E. Splittstoesser (Eds.), *Compendium of methods for the microbiological examination of foods* (pp. 105–120). Washington, DC: American Public Health Association.

Rajagopal, S., Sudarsan, N., & Nickerson, K. W. (2002). Sodium dodecyl sulfate hypersensitivity of clpP and clpB mutants of *Escherichia coli*. *Applied and Environmental Microbiology, 68*, 4117–4121.

Ricke, S. C. (2003). Perspectives on the use of organic acids and short chain fatty acids as antimicrobials. *Poultry Science, 82*, 632–639.

Satin, M. (2002). Use of irradiation for microbial decontamination of meat: situation and perspectives. *Meat Science, 62*, 277–283.

Shokri, J., Nokhodchi, A., Dashbolaghi, A., Hassan-Zadeh, D., Ghafourian, T., & Barzegar Jalali, M. (2001). The effect of surfactants on the skin penetration of diazepam. *International Journal of Pharmaceutics, 228*, 99–107.

Sumarmono, J., & Rahardjo, A. H. D. (2008). Effects of decontamination using organic acids on total microbial number and qualities of poultry carcasses. *Animal Production, 10*, 129–134.

Surekha, M., & Reddy, S. M. (2000). Preservatives, classification and properties. In R. K. Robinson, C. A. Batt, & C. Patel (Eds.), *Encyclopedia of food microbiology* (pp. 1710–1717). New York: Academic Press.

Tamblyn, K. C., & Conner, D. E. (1997). Bactericidal activity of organic acids in combination with transdermal compounds against *Salmonella typhimurium* attached to broiler skin. *Food Microbiology, 14*, 477–484.

Tamblyn, K. C., Conner, D. E., & Bilgili, S. F. (1994). *Bactericidal activity of organic acids against Salmonella typhimurium attached to broiler skin*. Annual Meeting of the Institute of Food Technologists, June 25 –29, Atlanta, GA (p. 170).

Tamblyn, K. C., Conner, D. E., & Bilgili, S. F. (1997). Utilization of the skin attachment model (SAM) to determine the antibacterial activity of potential carcass treatments. *Poultry Science, 76*, 1318–1323.

Van Immerseel, F., Russell, J. B., Flythe, M. D., Gantois, I., Timbermont, L., Pasmans, F., et al. (2006). The use of organic acids to combat *Salmonella* in poultry: a mechanistic explanation of the efficacy. *Avian Pathology, 35*, 182–188.

Xiong, H., Li, Y. B., Slavik, M. F., & Walker, J. T. (1998). Spraying chicken skin with selected chemicals to reduce attached *Salmonella Typhimurium*. *Journal of Food Protection, 61*, 272–275.

Yang, Z. P., Li, Y. B., & Slavik, M. (1998). Use of antimicrobial spray applied with an inside-outside bird washer to reduce bacterial contamination on prechilled chicken carcasses. *Journal of Food Protection, 61*, 829–832.

Zhao, T., Zhao, P., & Doyle, P. M. (2009). Inactivation of *Salmonella* and *Escherichia coli* O157:H7 on lettuce and poultry skin by combinations of levulinic acid and sodium dodecyl sulfate. *Journal of Food Protection, 72*, 928–936.